Opportunities for subsurface storage of CO, in Arizona may be classified Province and Basin and Range Geologic Province. The northwest trending provinces and has little potential for geologic storage.

The Colorado Plateau in northeast half of the state is underlain by a thick in the Palcozoic section that may be suitable for CO2 storage. The storage reservoirs are at depths ranging from approximately 3,000 to 7,500 feet and capped by thick and regionally-extensive shale confining beds. The Colorado Platea offers significant potential for geologic sequestration of CO2 although hydrologic

The Basin and Range province in the southwest half of the state consists of broad desert basins bounded by mountain blocks. The basins have been filled to depths of 5,000 feet or more with materials eroded from the mountain blocks. Although select basins may have favorable characteristics for geologic storage of

conditions and water quality is poorly known in all but the uppermost aquifer

Arizona-based utilities that operate four large coal-fired power plants in northeastern Arizona are sponsoring a pilot project to evaluate CO, injection and storage in the Colorado Plateau region with West Coast Regional Carbon Sequestration Partnership (WESTCARB). Based on screening of regional geologic and hydrologic conditions and considerations of land access and mitting, a site at or in the vicinity of the Cholla Power Plant near Joseph City Arizona was selected for a future demonstration project. This paper presents th findings of a preliminary evaluation of the potential for geological storage of CO, in Arizona and siting studies for the Arizona pilot project.

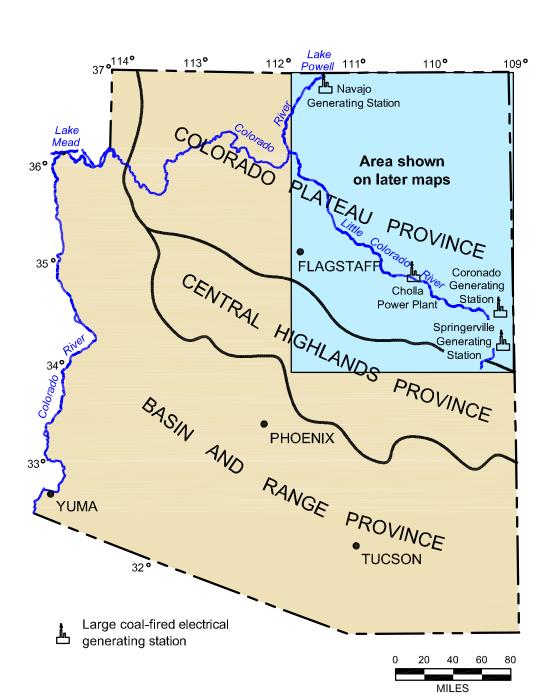


Figure 1. Colorado Plateau Regional Study

Geologic Unit	Age	Thickness (feet)	Description	Remarks		
Carmel Fm.	Jurassic	65 - 260	Claystone and sandstone	Confining bed beneath Black Mesa		
Navajo SS.	Jurassic & Triassic	100 – 1,000	Fine to medgrained colian sandstone; porosity 25-30%	Potential reservoir beneath Black Mesa but groundwater contains <1,000 TDS		
Kayenta, Wingate, Moenave Fms.	Triassic	650 - 820	Mudstone, siltstone, and sandstone	Primarily serve as confining beds in S. Black Mesa area		
Chinle Formation	Triassic	330 - 1,300	Primarily bentonitic mudstone; some sandstone and conglomerate	Excellent confining seal in much of NE Arizona		
Moenkopi Formation	Triassic	100 - 300	Siltstone and sandstone	Not considered an effective confining seal		
Coconino – DeChelly Sandstones	Permian	330 – 1,000	Fine to medgrained colian sandstone	A major potential reservoir in much of NE Arizona; groundwater contains >10,000 TDS in 8,000 km ² of southern Black Mesa area		
Hermit Shale - Organ Rock mem. of Cutler Fm.	Permian	100 - 330	Primarily siltstone with sandstone lenses	Confining seal in Grand Canyon- Black Mesa area		
Esplanade mem. of Supai Fm. – Cedar Mesa mem. of Cutler Fm.	Permian	65 - 650	Permeable sandstone with siltstone facies	Potential reservoir; not present in SE part of area shown on Figures 2 and 3		
Lower Supai Fm.	Pennsylvanian	330 - 800	Siltstone, sandstone, and limestone; extensive halite beds in SE Black Mesa basin	Acts as both confining seal and potential CO ₂ reservoir		
Redwall Limestone, Temple Butte Limestone, and Martin Formation	Mississippi & Devonian	500 – 1,000	Primarily limestone and dolomite; cavernous in Grand Canyon area	Potential reservoir; not present in SE part of area shown on Figures 2 and 3		
Tapeats Sandstone	Cambrian	165 – 400	Feldspathic, micaceous sandstone	Potential CO ₂ reservoir		

Table 1. Geologic Reservoirs and Seals in Colorado Plateau Province, Arizona

Potential Confining Bed, Chinle Formation Near Chinle, Arizona

Large coal-fired electrical generating stations are presently operating

Opportunities and potential for subsurface storage of CO2 in Arizona may be classified with respect to regional geologic conditions. The

at four sites in northeastern Arizona. The combined carbon dioxide (CO₂)

discharge at these stations in year 2000 was approximately 42 million tons

northeast half of the state is in the Colorado Plateau Geologic Province and

the southwest half of the state is in the Basin and Range Geologic Province The northwest trending mountainous area of the Central Highlands transition

zone occurs between the two provinces has little potential for geologic

storage. Locations of the provinces and of large coal-fired electrical

The Colorado Plateau is a high plateau region where landforms are

dominated by buttes, mesas, deeply incised canyons, and volcanic peaks.

Much of the Colorado Plateau is underlain by a thick sequence of nearly flat-

lying sedimentary strata interrupted at places by faults and gentle folds. The

existing coal-fired generating stations and the extensive Navajo and Hopi

Indian Reservations occur in Colorado Plateau Geologic Province. The

Colorado Plateau offers significant potential for geologic sequestration of

CO, The Arizona Geological Survey estimates that saline aquifers in deep

sedimentary units underlying the Colorado Plateau may have the capacity to

The Basin and Range province consists of broad desert basins

Province comprise tectonically depressed troughs and have been filled to

depths of as much as 10,000 feet with materials eroded from the mountain

blocks. This province includes the large cities of Phoenix and Tucson and

uma region in southwest Arizona and massive salt deposits existing in

select basins in southern and western Arizona, the Basin and Range province

more than 70 percent of Arizona's population. With the exception of the

has little apparent potential for geologic sequestration of CO₂

generating stations in Arizona are shown on Figure 1.

potentially store over 20 million metric tons of CO,

Colorado Plateau Geologic Province

Basin and Range Geologic Province

West

wo smaller coal-fired power plants are located in southeast Arizona.

COLORADO PLATEAU SITING STUDY

Errol L. Montgomery & Associates was asked to assist WESTCARB and the lead industrial partner, Salt River Project (SRP), to evaluate potential sites in the Colorado Plateau province for an Arizona pilot CO, storag project. Four specific sub areas were considered as areas of interest fo evaluation of CO, storage options in this region, including: · area north and west of the Coronado Generating Station · area south and east of Navajo Generating Station

ERROL L. MONTGOMERY

& ASSOCIATES, INC.

area generally encompassing Black Mesa • area of highly saline groundwater north of Cholla Power Plant Locations of the sub areas are shown on Figure 2. The northeast portion of the Colorado Plateau within Arizona in the vicinity of the Four Corners area is also a potential area of interest for CO, storage. However, this area was not included in this study due to consideration that its' characteristics may be comparable to areas investigated in southeastern Utah as part of the Southwest Regional Carbon Sequestration Partnership.

Favorable geologic and hydrologic conditions for storage of CO₂ occur in potential storage reservoirs of Cambrian through Permian age. Stratigraphy and structural geology of the potential reservoir units ar reasonably well known and correlated in outcrop and isolated deep exploration wells occurring in the Colorado Plateau. Hydrologic conditions and water quality within the potential reservoirs, on the other hand, are poorly known. These geologic formations together with mudstone strata that serve as overlying capping or confining units are summarized in Table 1.

The most favorable targets for sequestration in the Arizona section of the Plateau Province exist in clastic units underlying the Black Mesa basin beneath the Navajo and Hopi Indian reservations and in the vicinity of the Navajo Generating Station. The area in the vicinity of Cholla Power Plant is also potentially favorable for supercritical CO2 storage, although target reservoirs are more heterogeneous carbonate/clastic units at shallower depths. Depths of burial and reservoir properties diminish in the area northwest of Coronado Generating Station such that there is marginal potential for CO₂ storage. Geologic conditions and the presence of naturally occurring CO2 do not favor geologic storage in the vicinity of Springerville Generating Station. Potential storage reservoirs in the areas of interest and petrophysical properties associated with the target reservoirs are shown in **Table 2**.

(Bend in Section)

Navajo Sandstone

Chinle Formation

Kaibab Limestone - Coconino Sandstone

Hermit - Organ Rock Shale

Esplanade member of Supai Formation

Lower Supai Formation Mississippian and Devonian Limestone

Pre-Cambrian Rocks

FOR POTENTIAL GEOLOGIC STORAGE

OF CARBON DIOXIDE IN ARIZONA

Figure 2. Areas of Interest for Potential Geologic Sequestration of CO₂

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SUB-AREA	POTENTIAL RESERVOIR AND LITHOLOGY	ESTIMATED DEPTH TO TOP OF UNIT (feet bls)	THICKNESS (feet)	FORMATION PRESSURE (w.r.t. CO ₂)	INFERRED POROSITY	EXPECTED WATER QUALITY
Coronado Generating Station	Lower Supai Fm siltstone, mudstone, sandstone, evaporites	~ 2,700 (in area northwest of CGS)	800+	likely sub-critical	2 - 5% Primary	highly saline
Cholla Power Plant	Martin Fm dolomite and limestone, siltstone, mudstone	3,600 - 4,600	400	super-critical	10 - 20% Secondary	saline
	Naco Fm limestone, sandstone, mudstone	3,200 - 4,100	400 - 500	sub-critical to super-critical	10 - 20% Secondary	saline
Navajo Generating Station	Tapeats Sandstone medium to coarse sandstone	6,500 - 7,500	300	super-critical	5 - 10% Primary	likely saline
	Devonian/Mississippian carbonates limestone, dolomite	5,800 - 6,300	800	super-critical	10 - 20% Secondary	unknown
	Cedar Mesa Sandstone sandstone, siltstone	4,000	300	unknown	15 - 25% Primary	unknown
Black Mesa	Tapeats Sandstone medium to coarse sandstone	6,300 - 7,300	250	super-critical	5 - 10% Primary	likely saline
	Devonian/Mississippian carbonates limestone, dolomite	5,500 - 6,500	800	super-critical	10 - 20% Secondary	unknown
	Cedar Mesa Sandstone sandstone, siltstone	4,500 - 5,500	300	unknown	15 - 25% Primary	unknown

Table 2. Potential Reservoirs for CO₂ Storage in Sub Areas of Colorado Plateau Province

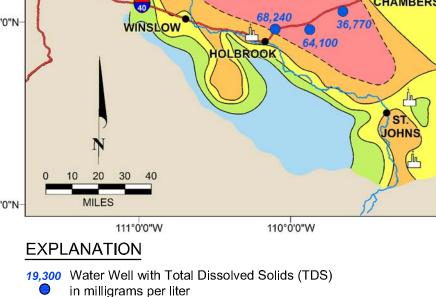
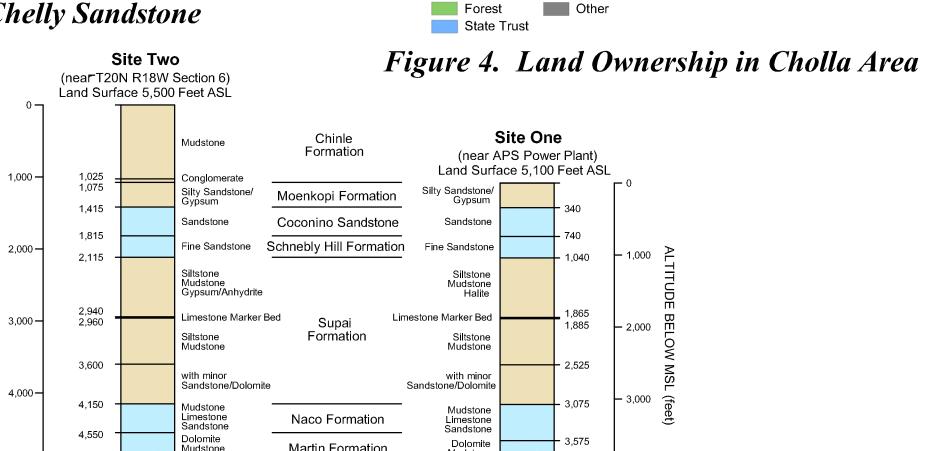


Figure 3. Distribution of TDS in Coconino / DeChelly Sandstone



EXPLANATION

Oil and Gas Deep Well (>3,000 foot total depth)

Triassic Chinle Formation. Target storage reservoirs throughout the Cholla

Site One would be located on APS property in the vicinity of the

Cholla power plant. This site offers the principal advantage of ease of

implementation in terms of arranging access and permission to conduct the

drilling of pilot well and facilitation of injection test. In addition, review of

geophysical logs indicates that the primary target reservoir, the Martin

Formation may be sandier (more porous and permeable?) at Site One,

Site Two would be located in T20N, R18E, perhaps in Section 2, 4, 8,

or 10, which are all state-owned sections. The site would be east of State

Route 87 and south of the Navajo Reservation. This site is suggested

because it offers: (1) relatively thick sections of Martin and Naco

Formations, (2) hydrostatic heads would be relatively large, (3) access to

near the site on paved roads, (4) presence of state-owned land, (5) two

In summary, Site One near the APS power plant has the potential

advantage of fewer injection site ownership and permitting problems, and

the disadvantage of lesser depths to potential storage reservoirs, and smaller

reservoir thickness. Site Two, 15 miles northwest of the power plant, has

the advantages of larger reservoir depths and thicknesses. For both sites,

paved access is available to lands that might be considered for an injection

site. From a technical standpoint, Site Two, near the Ives Mesa Dome, is the

anticlinal structures and, (6) it is relatively distant from communities.

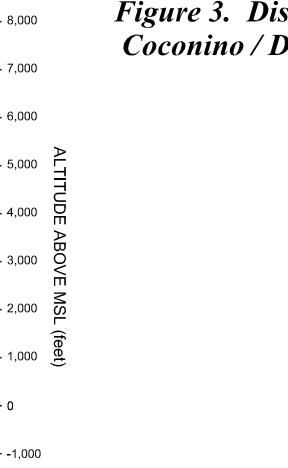
Area would be the Pennsylvanian Naco Formation and the Devonian Martin Formation (primary target). Inferred geology at these sites is shown in

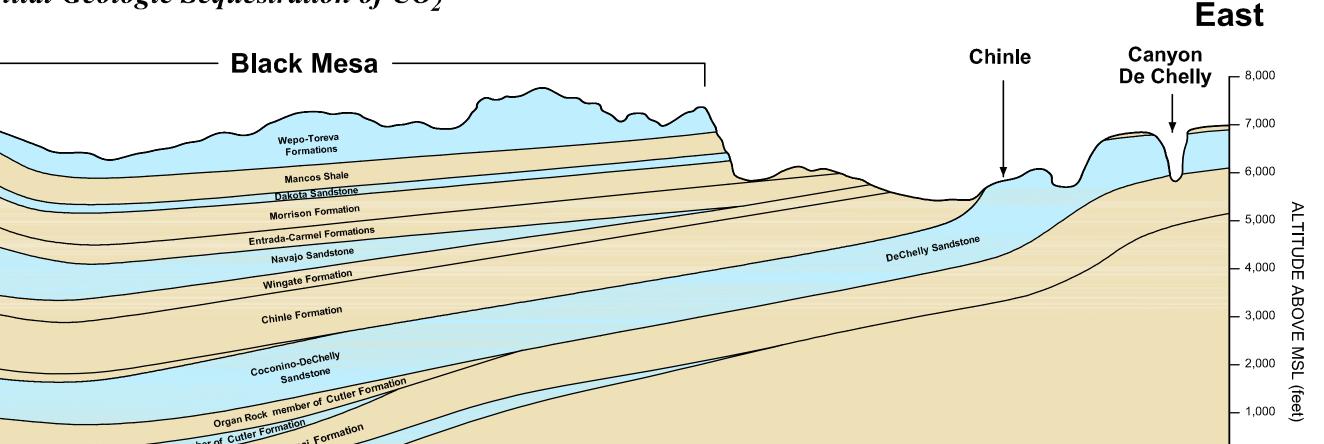
Discussion of Proposed Demonstration Sites One and Two

because it is nearer the Devonian depositional shoreline.

superior location for a pilot injection test.

Pre-Cambrian





Geologic Cross-Section from Colorado River, Through Black Mesa, to Canyon de Chelly

PRELIMINARY EVALUATION AND SITING STUDIES WESTCARB project objectives, the Cholla Area (see Figure 2) was prioritized for potential consideration for the Arizona demonstration project Two important factors were pivotal in selecting the Cholla Area for further consideration. First, the Cholla Area is the most favorable area in the

Colorado Plateau under consideration in lands outside of the Navajo Nation and Hopi Indian reservation. Oil and gas test wells drilled in this area indicate that most of the Cholla Area appears favorable for supercritical carbon dioxide storage, whereas areas to the east in the vicinity of the Salt River Project (SRP) Coronado Generating Station are less favorable. Effort undertaken by SRP and WESTCARB to engage the Navajo Nation to participate in the Arizona demonstration project indicated timely Tribes would be problematic.

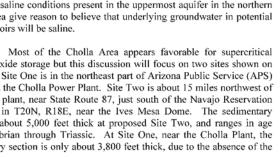
SITE SELECTION FOR ARIZONA DEMONSTRATION PROJECT

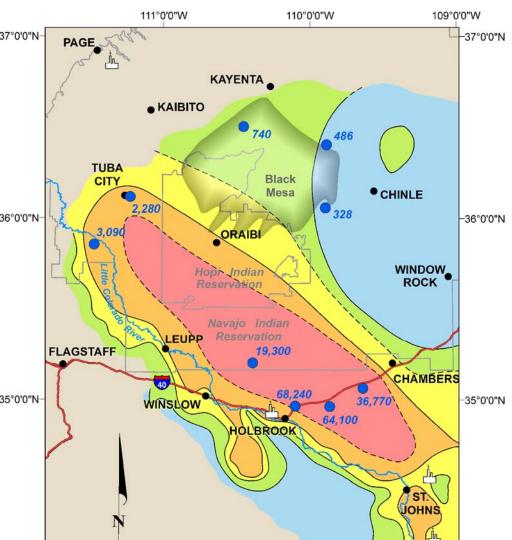
Based on the screening and evaluation of potential CO2 storage sites

Coconino/De Chelly Sandstone. As shown in Figure 3, groundwater wells penetrating the regional aquifer indicate an extensive area of poor quality groundwater exists just north of and roughly parallel to the Little Colorado approximately 20,000 to 70,000 milligrams per liter in this area due to the presence of evaporative salts in the underlying Supai Formation. Although the highly saline conditions present in the uppermost aquifer in the northern Cholla Area give reason to believe that underlying groundwater in potential

carbon dioxide storage but this discussion will focus on two sites shown on Figure 4. Site One is in the northeast part of Arizona Public Service (APS) property at the Cholla Power Plant. Site Two is about 15 miles northwest of the Cholla plant, near State Route 87, just south of the Navajo Reservation boundary, in T20N, R18E, near the Ives Mesa Dome. The sedimentary section is about 5.000 feet thick at proposed Site Two, and ranges in age from Cambrian through Triassic. At Site One, near the Cholla Plant, the sedimentary section is only about 3,800 feet thick, due to the absence of the

implementation of the pilot project on lands of the Navajo or Hopi Indian A second key factor supporting pilot project implementation in the Cholla Area was based on water quality of the regional aquifer in the River in this region. Total dissolved solids in groundwater range from





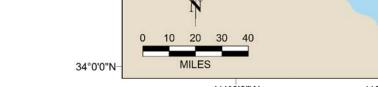


Figure 5. Inferred Geology in Cholla Area